China and the Environment: The Challenges Ahead, Solutions, and Future Research

By Gregory C Chow and Jie Li, Princeton University

1. Introduction

A workshop of the above title on China's energy and environmental problems was convened at Princeton University on April 18-19 2008. One purpose of the workshop was to promote exchange and possible cooperation between Princeton and Chinese institutions as a part of the University's internalization initiative. The initiative was outlined in a report issued in October 2007 by President Shirley Tilghman and was based on recommendations by a committee of Princeton faculty members. The second purpose was to share knowledge and experience in solving energy and environmental problems in China and in the United States which might be useful for future research and policy formulation in both countries. The topic was chosen in recognition of its importance to China and to Princeton University.

The workshop was organized by Gregory C. Chow of the Departments of Economics and Operations Research & Financial Engineering, Michael Celia of the Department of Civil and Environmental Engineering and Alexander Smits of the Department of Mechanical and Aerospace Engineering. It consisted of three sessions chaired by the workshop organizers and a session summarizing the findings from the workshop presentations. The first session dealt with energy-environment policies, while the second and third dealt with technical aspects of environmental protection and clean energy. Considering the nature of this Journal we will concentrate our report on the first session, "Regulations of Pollution and Environmental Damage."

The following is the agenda of the energy-environment policy session, which took place on April 18, 2008.

Welcoming Remarks

8:30 Shirley M. Tilghman, President, Princeton University

Session 1. Regulations of Pollution and Environmental Damage

Chair: Gregory C. Chow, Departments of Economics and Operations Research & Financial Engineering, Princeton University

8:40 Zou Ji, School on Environment and Natural Resources, Renmin University of China
Strategies to Coordinate Economic Development, Energy Use, and Emission Control in China

9:00 Smita Brunnermeier, Woodrow Wilson School of Public and International Affairs, Princeton University
Lessons Learned from the U.S. Experience with Regulating Environmental Pollutants

9:20 He Jianwu, Development Research Center, State Council
Li Shandong, Development Research Center, State Council
The Impact of Energy Tax/Environmental Tax on China's Economy

9:40 Xu Zhao, School of Economics, Shanghai Jiao Tong University
Energy Tax: The Case of Fuel Oil Tax

10:00 **Coffee Break**

10:30 James Wei, Department of Chemical Engineering, Princeton University
Carbon Emission and China

10:50 Minjun Shi, Research Center on Fictitious Economy and Data Sciences, Chinese Academy of Sciences
Effects of Policy on Energy Saving and Pollution Reduction on Regional Economic Development in China (co-authors Na Li and Qiang Liu)

11:10 Yuan Xu, Woodrow Wilson School of Public and International Affairs, Princeton University
China's SO2 Scrubber Story and Its Implications for Carbon Mitigation

11:30 **Panel Discussion**
Moderator:
Burton Malkiel, Department of Economics, Princeton University

Panelists:
Yong Shi, Graduate School of Management, Chinese Academy of Sciences

Rene Carmona, Department of Operations Research & Financial Engineering, Princeton University

Li Shandong, Development Research Center, State Council

Gregory C. Chow, Departments of Economics and Operations Research & Financial Engineering, Princeton University

President Shirley Tilghman recognized the importance of this workshop to Princeton University in her opening remarks, which we quote in part: "it is my pleasure to welcome you to a workshop focusing on a most important set of topics: the environmental problems facing China; technological and policy solutions available today; and leading-edge research that has the potential to transform these challenges in the future…"

President Tilghman, who visited universities in Singapore and Shanghai during her trip through Asia in March 2008, pointed out the importance of international communication and cooperation:

> Last fall, Princeton launched a major initiative to strengthen the international dimension of education and research at our University … we in the United States are increasingly affected by ideas developed and decisions made outside our borders. If Princeton is to participate fully in the challenges and opportunities of globalization, we must create new channels for international exchange, and we must form new partnerships, beyond the circle of institutions with which we have traditionally interacted. This workshop represents the kind of international bridge-building and collaboration that Princeton is committed to pursuing in the 21st century.

She also stressed the meaning of collaboration on environmental and energy issues:

> Environmental problems powerfully reveal the interconnectedness of the modern world and the insufficiency of purely national or sub-national responses. The energy-consumption habits of the developed world have clearly altered the global climate system, affecting the lives of billions of people in ways that we are only beginning to understand. Future decisions about energy use and greenhouse gas emissions—especially decisions made in rapidly-modernizing nations such as China—will also affect the course of climate change, for better or for worse. Likewise, we are learning that environmental problems once considered local, such as air pollution, may have regional and even hemispheric impacts.
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> As the international community's largest emitters of greenhouse gases, the United States and China have a special responsibility to work together to secure a greener future for our planet. The many Princeton scientists and engineers who are working on environmental problems welcome opportunities to learn from their colleagues in China—and vice versa. It is my sincere hope that all of you will return home with new insights into difficult environmental problems and potential solutions to them, as well as a new sense of the promise of international intellectual collaboration.

2. Papers presented in Session 1: Regulations of Pollution and Environmental Damage

In describing “Strategies to Coordinate Economic Development, Energy Use, and Emission Control in China”, Zou Ji of Renmin University employed a model LEAP (Stockholm Environment Institute (SEI), 2008) to generate different energy consumption and CO2 emission scenarios. Underlying assumptions for GDP and population growth rates, urbanization, economic structure, and energy structure are made for 2020, 2030, and 2050. Professor Zou examined two scenarios which differed in the assumptions of the economic structure and share of renewable and nuclear energy within the total energy demand. Under the BAU scenario, China’s energy consumption is projected to be 4.4 billion tce in 2020 and 5.8 billion tce in 2050. In comparison, under the Action-taking scenario, China’s projected energy consumption is reduced to 3.9 billion tce in 2020 and 5.0 billion tce in 2050. CO2 emissions under the two scenarios are projected to be 12 and 9.8 GtCO2 in 2020 respectively (13.2 and 10.5 GtCO2 in 2050 respectively). Several technological options in energy/emission-intensive sectors, such as power, transport, housing, cement, ferrous and non-ferrous metallurgy, chemical products, and petroleum refining were analyzed in terms of emission reduction of GHGs and local pollutants, cost, and maturity of technologies. In addition, Zou Ji proposed a framework to achieve the combined objectives of development, energy-global warming control, and addressing local government concerns regarding the effect of environmental policies on economic development.

Thus the model can be used in designing a strategy to achieve the objectives of development, energy-emission reduction, and dealing with local environmental concerns. The method is similar to the method of optimal control used for macro-economic policy analysis. The latter method also uses a model to simulate economic consequences under alternative policies. A policy is chosen that would achieve the objectives desired. Needless to say, the usefulness of either method depends on how good the model is. Also, the key to an informed comparison between the BAU scenario and the action-taking scenario is contingent on the design of the two scenarios. The basic assumptions behind each scenario determine, to a very large extent, what the major conclusions would be.

The second paper "Lessons Learned from the U.S. Experience with Regulating Environmental Pollutants" by Smita Brunnermeier of the Woodrow Wilson School and the Department of Economics at Princeton University, reviews environmental instruments used in the U.S. for pollution regulation. In summary, Dr. Brunnermeier suggests that no single policy instrument or set of instruments will always provide the best solution. An interesting finding from the presentation is the requirement for polluters to submit information on pollution (an emissions inventory) to the public as a way to help reduce pollution. Lessons learned on information submission are: 1) Up-front investments in monitoring and enforcement capability are essential; 2) It is necessary to establish programs to disseminate information while also threating mandatory abatement in order to provide firms with incentives for pollution reduction. Another important lesson is that cap and trade is most useful when compliance costs vary across polluters because the trading of emission permits helps to equalize the marginal costs of pollution among polluters.

Lessons learned on innovation are also worth serious consideration by policy makers. Dr. Brunnermeier identified four points, which are the following:

1) Diffusion is an integral part of innovation and requires attention;
2) Avoid "freezing" a particular technology by prohibiting further innovation.
3) Prefer "open-ended" pull strategies to encourage innovation.
4) Avoid picking winners in subsidizing specific types of possible innovation in an early stage of a technology race.

In the third paper "Economic Growth, Environmental Protection and Environmental Tax" Li Shantong and He Jianwu from the Center for Development Research at the State Council, studied the impact of environmental tax policies on the achievement of the goal in "11th Five-Year-Plan" and long-term sustainable economic development. This paper used a computable general equilibrium (CGE) model to study the impact of different energy/environmental taxes on economic growth, income distribution, energy consumption and environment, etc. Four different policy scenarios were designed; they are based on a combination of assumptions regarding whether the tax is imposed on

primary energy or SO2 emissions and whether the tax revenue designed will reduce corporation income tax or business tax for service. Impacts on GDP, investment, household consumption and income, and employment are analyzed under each scenario for different SO2 reduction targets (5%, 10%, 15%, or 20%). The conclusions are the following: 1) ax on emission is more effective than on energy; 2) nergy tax brings larger loss to urban households relative to rural; 3) ax recycling also plays a key role; 4) xpansion of energy-intensive industries can be effectively constrained by energy/environmental policies, while labor-intensive sectors will benefit.

One may ask, if only the results of model simulations are reported, what can we learn?

We can trust the results if we understand the major hypotheses imbedded in the model and how the model incorporates these hypotheses. The results are more believable if policy analyses using the model have been successful in the past. We would also like to find out why different environmental taxes were enacted and the degree of success in their enforcement.

The fourth paper “Energy Tax: The Case of Fuel Oil Tax” by Xu Zhao from the Antai College of Economics & Management at Shanghai Jiao Tong University also deals with the topic of energy tax. Her presentation points out that 68.9 percent of the energy in China comes from coal while 21.0 percent comes from oil. A tax on the use of coal appears politically unacceptable because it affects a large number of poor consumers. In 1997, National People’s Congress (NPC) passed the Bill of Roads, which first mentioned the use of fuel oil tax to replace the fees for road maintenance. Furthermore, NPC wanted to implement the fuel oil tax beginning January 1, 1998. But after ten years of debates, the tax has not been put into effect. This paper analyzes from the perspective of resistance from groups with vested interests as well as the obstacles to the implementation of fuel oil tax in China. It also provides several policy recommendations to resolve these conflicts.

The analysis is based on the presupposition that different interest groups accept the policy only when it will not affect their interests adversely. To understand the “vested interest” problem this paper considers three interest groups: 1) the final individual consumers, by

comparing the burden of fees collected from using highways and fuel oil tax for the consumers; 2) selected industries such as agriculture and taxi service industry; and 3) different departments of the central government and local governments and the reallocation of interest and power among them. Policy recommendations in the paper include: 1) The fuel oil tax introduced should not be more costly to final consumers than the existing fees that it replaces; 2) Local governments should be empowered to levy the fuel oil tax directly; 3) setting a new system for measuring the fuel oil tax burden on taxi-cabs; and providing subsidy to public transportation. From this paper we note the long delay between the enactment of the tax and its implementation because of the resistance from vested interest groups. In the United States, interest groups also cause delays in or even prevent the adoption of tax on energy, including gasoline tax; however, the delay occurs in the legislative rather than the implementation stage. U.S. legislators consider the interests of their constituents before passing a bill to tax them, whereas Chinese government officials may wish to have a law passed according to their policy objectives and leave implementation of the law to a later stage.

Another paper of interest is “China’s SO2 Scrubber Story and Its Implications for Carbon Mitigation” by Yuan Xu from Princeton University’s Woodrow Wilson School. China’s rate of installing SO2 scrubbers has overtaken that of building new coal power plants. This activity, along with several other initiatives, makes it likely that China will achieve its ambitious 10% SO2 emissions reduction goal set forth in its 11th Five-Year Plan.

The commercial availability of SO2 scrubber technologies, China’s rapidly growing economy, its technological capacity underpinning its economic strength, and unprecedented attention to environmental protection by China’s top leaders are all factors that have enabled this rapid deployment of scrubber technology.

China’s demonstrated capability to respond quickly to the SO2 pollution challenge could have far-reaching implications for other pressing environmental challenges such as carbon mitigation, This is especially true for the deployment of CO2 capture and storage (CCS) technology, a key carbon mitigation option for coal-intensive energy economies such as China’s. Regarding this claim by Yuan Xu, ZOU Ji from Renmin University

raised two important points. First, the cost of CCS is much larger than that of the installation of SO2 scrubbers. Second, the difficult choice of locating carbon storage sites is another challenge that SO2 technology does not have to face.

In the panel on environmental policies, Gregory Chow from Princeton University presented "A Proposal to Improve the Regulation of China's Air and Water Pollution." His proposal consists of the following four components:

(1) For each case of air or water pollution the local office of the Ministry of Environmental Protection issues a fixed number of emission permits per quarter. Each polluter is required to report the amount of pollution during the quarter and to pay for a number of permits equal to the amount of pollution reported.

(2) Given the number of permits issued, demand by polluters will determine the price per permit. The Administration's local office will first set an initial price for the permits. If the price is too low, the permits will run out and some polluters need to purchase them from others. If the initial price is too high, there will be unsold permits and the local office will lower the price until all permits are sold.

(3) In determining the number of permits to issue in each local area affected by the pollution, the local office solicits and respects suggestions from the directly elected village heads in rural areas and the directly elected representatives in urban areas.

(4) The revenue received from the permits will be returned to the local government of the area affected. Under the proposal the local residents through their representatives and the local government will have an incentive not only to determine a suitable amount of pollution permitted but to help enforce the amount.

This proposal provides a general scheme for environmental regulation. It needs to be adopted to suit the particular conditions of pollution in specific cases. For a specific case, more details in monitoring and enforcement are required. It is understood that different local regulations may cause migration of some pollution-intensive industries but such migration is desirable as pollution intensive factories move to localities that are willing to accept more pollution. It is also understood that water pollution in one locality may affect

the communities downstream; this would require expanding the area in applying the proposed scheme. Air pollution can also move outside the locality that adopts the above regulation scheme, but this assume that the self interest of the locality adopting the above regulation scheme is sufficient to limit pollution to a suitable amount, just as a smoker's self interest in protecting his or her own health is sufficient to limit the amount of his or her smoking without regard to the possible effect on the health of people nearby. Given these considerations, some communication and collaboration among local environmental protection agencies still may be desirable. In order to propose more effective regulations, this proposal can be combined with other instruments when appropriate.

From the technical sessions we have selected one paper to report: the paper "Research in Zhejiang University related to China's energy-environmental problem by Kefa Cen, Mingjiang Ni, and Jun Cheng of Zhejiang University. The research in Zhejiang University, as with the research in other major universities in China, aims to upgrade China's energy structure, increase efficiency to save energy, reduce the emissions of pollutants and develop new and renewable energy. At Zhejiang University, energy-environmental research covers the following fields:

(1) Clean Efficient Utilization of Fossil Fuel: clean coal combustion, near zero emissions in coal poly-generation utilization, clean efficient utilization of liquid and gas fuel.

(2) New Energy and Renewable Energy System: biomass gasification and liquefaction for clean fuel, biomass efficient combustion, efficient conversion of solar energy, hydrogen energy production from solar energy and biomass.

(3) Clean Utilization of Low Grade Energy: waste incineration, hydrolysis and gasification, environmental friendly energy recovery from waste, waste heat recovery.

(4) Pollutants Formation, Transmission, Measurement and Control during Energy Utilization: SOx /NOx /fine particles /trace pollutants and CO2 formation and control, simultaneous removal of multi-pollutants.

(5) Numerical Simulations and Advanced Measurements in Multiphase Reaction System: optimization of design and operation in energy conversion systems based on computer

aided test, direct numerical simulation on turbulent flows in multiphase complicated reaction system, advanced measurements and diagnostics techniques for combustion.

3. Summary of Papers Presented in Session 1

To summarize the findings of Session 1, it is useful to organize our discussion of energy-environmental problems by the following table of two targets (objectives) and three instruments (solutions):

Instruments/Targets	**A. Reduce Energy/Output**	**B. Reduce Emission/Energy**
1. Regulation and planning (Command-and-control)	• Target in 11th Five-Year Plan to reduce energy output ratio • Efficiency standards	• Target in 11th Five-Year Plan to reduce emission of air pollutants • Emissions standards for SO2, NOx, PM, CO2 …
2. Economic incentive	• Energy tax • Subsidy	• Environmental tax • Trading emission permits (cap-and-trade demonstration for SO2)
3. Introduce and promote new/clean energy technology 3.1. Government 3.2. Market	• Energy efficient technology for production and consumption	• Solar, wind, hydro, nuclear energy • Carbon capture and storage

The objectives are to reduce the amount of energy use per unit of output (or energy intensity) and to reduce the amount of emission of pollutants per unit of energy used. There are three methods to achieve these objectives. Given the existing technology, we can use the method of regulation and planning (command-and-control), or the method of providing economic incentives such as taxation and subsidy. Thirdly, we can introduce and promote new and clean technologies to reduce energy intensity and the amount of emission.

On the Use of Instrument 1: Regulation and Planning (command-and-control)

1a. The Chinese government tends to emphasize instrument 1: to reduce energy/output and emission/energy by setting planning targets and by regulation.

1b. It is important to estimate the costs and benefits of environmental protection. The costs include the reduction of output and the cost in monitoring and enforcement. China discontinued the publication of green GDP but a method of estimation can be used to perform a cost and benefit analysis.

1c. The problem of enforcement and implementation is serious, as illustrated by the failure in achieving the targets to reduce energy intensity and pollution in the first two years of the 11th Five Year Plan.

1d. Computable general equilibrium, input-output and other models are used to evaluate impacts of alternative polices as an aid to develop planning strategies, as exemplified by the presentation of Zou Ji, Li Shantong and He Jianwu, and Minjin Shi.

On the Use of Instrument 2: Economic Incentive

2a. China is experimenting with using instrument 2: the use of economic incentives, including energy tax and environmental tax – Li Shantong, He Jianwu, and Zhao Xu.

2b. The U.S. has obtained valuable experience in using instrument 2.The use of economic incentives can be an effective and efficient way to achieve the targets. The requirement for polluters to submit information on pollution to the public can help reduce pollution. Cap and trade is most useful when compliance costs vary a lot across polluters – Smita Brunnermeier.

2c. Energy/Environment Tax: The introduction of such a tax is subject to the entitlement problem of the users who have to pay more. In designing an energy tax that resists interest groups has to be taken into account. An energy tax encourages the reduction in the use of energy but not the limitation of pollution for a given amount of energy used. Local governments know different local conditions and may be able to impose levies on pollution more successfully – Zhao Xu.

2d. Policy to subsidize the use of energy efficiently and the use of clean energy has a higher chance of success since it does not have to deal with the entitlement problem.

2e. For the regulation of air and water pollution, a proposal suggests that: (1) the local office of the State Environmental Protection Ministry require all polluters to report the amount of pollution and pay for it by emission permits; and (2) local residents through their publicly elected representatives be given a voice in determining the total quantity of permission permits, while the demand given the quantity supplied would determine the price. This proposal enables the local residents to help determine the optimum amount of pollution through rational calculations and to help enforce that amount – Gregory Chow.

2f. There is the lack of study on more flexible instruments, such as cap-and-trade, for China. Further research is still needed on application of flexible economic instruments, lessons from environmental regulation of other countries, and evaluation of SO2 cap-and-trade demonstration in China. Cap and trade of emission permits can be an effective means to limit CO2 emission if properly designed, as illustrated by Rene Carmona of Princeton University in a study of using emission permits to control CO2 emission in Europe.

On the Use of Instrument 3: Introduce and Promote New/Clean Energy Technology

3a. New Technology: We can be optimistic and expect much successful development in China because China has excellent research institutions and the government is willing and has sufficient funds to promote and encourage research. This expectation is justified by the successful introduction of new technology and the successful research to develop new technology as illustrated by Yuan Xu's presentation on the SO2 scrubber story and the results of research obtained by leading Chinese institutions including those represented in this workshop.

3b. As suggested by ZOU Ji, international technology cooperation should be a focus in discussions of international climate change regime beyond 2012, and be promoted even before the formulation of any bounding regime.

3c. Sessions 2 and 3 as briefly described below cover some of the significant research already achieved and the promising areas of future research.

4. Remaining Sessions

The remaining parts of the workshop schedule are the following:

Afternoon Session: 2:00 – 5:30 p.m. on April 18

Session 2. Energy and Environmental Issues I

Chair: Michael A. Celia, Department of Civil and Environmental Engineering, Princeton University

2:00 Zifa Wang, Nansen-Zhu International Research Center, Institute of Atmospheric Physics, Chinese Academy of Sciences
Development of Air Quality Ensemble Forecasting Model System for Beijing (EMS-Beijing)

2:20 James A. Smith, Department of Civil and Environmental Engineering, Princeton University
Urbanization and the Regional Precipitation Climatology of the Beijing Metropolitan Region

2:40 Kyle Meng, Environmental Defense Fund
A Common Challenge: Why China and the U.S. Must Break the Climate Deadlock Together

3:00 Peter R. Jaffe, Department of Civil and Environmental Engineering, Princeton University
Biogeochemical Processes in Wetland Sediments and Their Effect on the Fate of Trace Metals

3:20 **Coffee Break**

3:50 Kelly K. Caylor, Department of Civil and Environmental Engineering, Princeton University
Ecohydrological Approaches for Assessing and Addressing Dryland Degradation

4:30 **Panel Discussion**
Moderator:
Catherine A. Peters, Department of Civil and Environmental Engineering, Princeton University

Panelists:
Jun Cheng, College of Environmental and Energy Engineering, Zhejiang University, and Department of Chemistry, Princeton University

Hiram Levy II, Geophysical Fluids Dynamics Laboratory, and Department of Geophysical Sciences and the Program in Atmospheric and Oceanic Sciences, Princeton University

Mark A. Zondlo, Department of Civil and Environmental Engineering, Princeton University

Saturday, April 19, 2008

Registration and Coffee: 8:00 – 9:00 a.m.

Morning Session: 9:00 a.m. – 12:30 p.m.

Session 3. Energy and Environmental Issues II

Chair: Alexander J. Smits, Department of Mechanical and Aerospace Engineering, Princeton University

9:00 Mingjiang Ni, College of Environmental and Energy Engineering, Zhejiang University
Research in Zhejiang University Related to Energy-Environmental Problems in China

9:20 Emily A. Carter, Department of Mechanical and Aerospace Engineering, Princeton University
First-Principles Materials Design for Energy Conversion and Conservation

9:40 Yiguang Ju, Department of Mechanical and Aerospace Engineering, Princeton University
Alternative Fuels for a Carbon Constrained World (co-authors: Frederick L. Dryer, and Chung K. Law)

10:00 Yanqing Wu, School of Environmental Science and Engineering, Shanghai Jiao Tong University
Water Environmental Problems and Protection Strategies in China

10:20 **Coffee Break**

10:50 **Forum I: "Future Visions"**
Discussion Leaders:

Robert H. Williams, Princeton Environmental Institute, Princeton University

Robert J. Goldston, Princeton Plasma Physics Laboratory

11:40 **Forum II: "Lessons Learned"**
Discussion Leaders:

Robert H. Socolow, Department of Mechanical and Aerospace Engineering, Princeton University

Chung K. Law, Department of Mechanical and Aerospace Engineering, Princeton University

12:30 **Lunch**

Afternoon Session: 2:00 – 3:30 p.m.

Session 4. Summary of Findings

Regulations of Pollution and Environmental Damage: Gregory C. Chow

Li Shantong, Development Research Center, State Council

Yong Shi, Research Center on Fictitious Economy and Data Sciences, Chinese Academy of Sciences, and School of Management, Graduate University of the Chinese Academy of Sciences

Zou Ji, Department of Environmental Economics and Management, Renmin University of China

Energy and Environmental Issues: Alexander J. Smits

Jun Cheng, College of Environmental and Energy Engineering, Zhejiang University, and Department of Chemistry, Princeton University

Yanqing Wu, School of Environmental Science and Engineering, Shanghai Jiao Tong University

Concluding Remarks

Michael A. Celia, Department of Civil and Environmental Engineering, Princeton University

5. Important issues raised in the workshop

There were several notable opinions and policy recommendations suggested in the workshop, which should deserve attention from Chinese researchers and policy makers. As we understand them, they are the following:

First, how should China divide the responsibility for solving environmental problems into provincial or lower administrative levels?

There have been increasing interests in modeling China's economic and environmental problems at the regional level. Given the substantial differences among regions and the large size of each province in terms of population, geographic area, and GDP in China, it is reasonable to disaggregate China's energy and environmental problems into a smaller scale at the provincial level. During the summary of findings session on Saturday afternoon, Li Shantong remarked how it is easy to understand why we are working on China's energy and environmental issues but we still do not know what to do and how to address these issues. This workshop has given us a forum to contemplate these questions.

Further research on the cost of each policy and its economic impact will be important. Stimulated by Princeton professor Robert Socolow's presentation on a new international scheme for carbon burden-sharing, which will be discussed later in this paper, Prof. Li mentioned the importance of international cooperation in solving China's domestic environmental problems.

China has assigned its national emissions reduction and energy saving targets to each province, but no in-depth analysis exists of how the regional assignments are derived and how they can be implemented. There is an urgent need for such an analysis if regional targets are assigned. However, if an environmental protection scheme is decentralized and is not based on a central assignment, as Gregory Chow proposed above, to improve the regulation of air and water pollution, there is no need to assign regional targets. Local conditions then will determine the amount of pollution in each region or locality.

Second, in terms of policy instruments, we suggest that more consideration be given to market-based instruments.

At present there is still a strong preference to use command-and-control policy instruments in China. Research presented by the Chinese scholars indicate that interests are limited to energy and pollution tax when market-based instruments are considered . There is no presentation on cap-and-trade, although we know of an SO2 cap-and-trade demonstration in China. According to the experiences in the U.S., more flexible policy instrument can be economically more effective and efficient.

Smita Brunnermeier gave a very impressive presentation on the lessons learned from the experiences of American environmental regulation as we have reported above. Some points from her presentation deserve our serious attention. Policy objectives, such as target levels for emissions, should be achieved with the highest degree of certainty and at the lowest cost, while promoting technological innovation. She recommends the need for a clear and stringent legal standard, coupled with flexible policy instruments, and for innovation that responds to incentives, including regulatory pressures and market forces.

Third, there was much emphasis on cooperation to bring about technology breakthrough.

Zou Ji pointed out the urgency of technology transfer and cooperation in order to avoid the lock-in effects of "low efficiency technologies in infrastructure (transport, power, and buildings)."

Robert H. Williams of Princeton University expressed his enthusiasm for CCS. The topic of his presentation is "Getting Started with CO2 Capture and Storage (CCS) in the US and China: Opportunities for Collaborative Research?" He stressed the necessity and urgency of technology breakthrough of CCS for the following reasons:

1. China's heavy reliance on coal
2. CO2 capture and storage (CCS) is needed to sustain the substantial use of coal in a carbon-constrained world.
3. Without CCS, marginal CO2 emissions abatement cost increases significantly in pursuit of low-carbon energy in the future.
4. Urgency of getting started with CCS due to rapid growth in coal power generating capacity.

In the end, he raised the question, "as the two world leaders in coal energy conversion, can the US and China find ways to work together to carry our integrated CCS projects in both countries?" This discussion is consistent with Yuan Xu's earlier presentation on China's SO2 story and his optimistic prospect that a similar story for CCS may also occur in China.

Some participants raised additional concerns about the geographical capacity, reliability, and availability of water resources for gasification and carbon capture. Are we too optimistic about CCS? Are there real opportunities to meet the global challenges of CO2 emission? If yes, how are we going to collaborate to seize upon such opportunities?

Fourth, China's possible share of CO2 emissions reduction

Under the international pressure of climate change, the world is looking for schemes to achieve a more equitable allocation of the burden to reduce CO2 emissions. Robert Socolow proposed a burden-sharing scheme for international carbon mitigation allocation based on the CO2 emission responsibility for each individual person. No matter where a

person lives, each individual with CO2 emissions above a certain level will be held responsible for mitigation. Suppose we require all those with emissions above a particular threshold to reduce their CO2 emissions to the threshold in order to achieve a global target, the sum of all the high-emitters' reductions in a country is its total mitigation responsibility. One application of this scheme shows that to cap the global emissions at the level of 30 GtCO2/year in 2030, 1.1 billion people (almost divided evenly among the 4 major groups of regions) will be held responsible. The allocation results are shown in Table 2. As Professor Socolow remarked, "When we take climate change seriously, we develop a global identity."

Table 2. Four comparable assignments in 2030

	Reduction (GtCO2)	BAU → Target in 2030 (GtCO2)	Population counted as responsible (million)
USA	4.4	8.0 → 3.6	270
Rest of OECD	2.1	8.7 → 6.6	280
China	2.9	11.4 → 8.5	300
Rest of World	3.5	14.8 → 11.3	280

Will the amount (8.5 GtCO2/yr) for China be an acceptable national target of CO2 emissions in 2030? If so, how is China going achieve it? The figure might provide a magnitude of future carbon mitigation burden facing China.

This workshop may mark the beginning of a long-term cooperation on research and policy analysis for energy-environmental problems between Chinese institutions and Princeton University. Discussion is underway to institutionalize the cooperation by a website maintained by the School of Engineering and Applied Science at Princeton University and by the continuation of similar workshops in the future. The next workshop is being planned to take place in Shanghai in the later part of October, 2009. The organizers in China will include some of the institutions represented in this workshop and possibly others.